SUBRESOLUTION CLINOMETRY WITH MAGELLAN RADAR IMAGES: HEIGHT OF LAVA FLOW EDGES ON VENUS. ***M. A. Kreslavsky[1,2] and R. V. Vdovichenko[2],***

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A new method for estimations of heights and slopes of small-scale topographical features on Venus with Magellan radar images is proposed. The method is used for estimation of height of a step associated with some edges of digitate lava flows. Upper limit of such height is estimated for sheet flows.

Introduction and idea. Magellan radar altimeter gave topography of Venus with spatial resolution of 10...20 km [1], so these data can be used to study features ranged from ~ 20 km to the global scale. Heights and slopes of steep topographical features with typical lateral size of 1 km to 100 km can be estimated combining Magellan images taken at different looks [e.g., 2]. We propose a way that in some cases gives estimations of heights of small-scale (10...100 m) steep slopes. The idea of the method is quantitative assessment of the radar backscatter enhancement by steep small slopes faced toward radar. Below we illustrate how this idea works with one example.

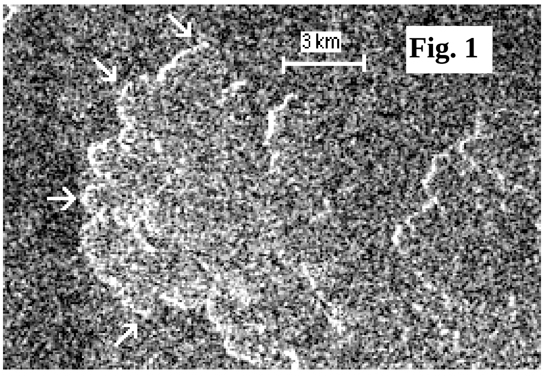

Fig. 1

Observations. Radar-bright and sometimes radar-dark patches with sharp lobate boundaries are very common on radar images of Venus surface. Their interpretation as lava flows is commonly adopted and undoubted [e.g., 3].

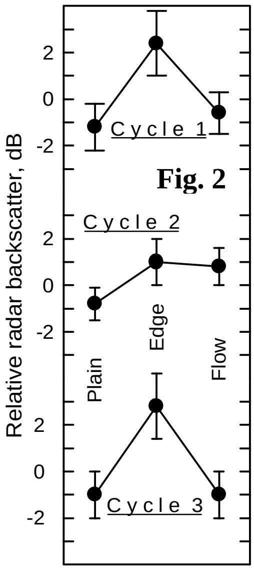

Fig. 2

Small area centered at 2.0^0 S, 151.7^0 E from a full-resolution Magellan mosaic is shown in **Fig. 1**. A set of overlapping lava flows is seen in the image. Left (Western) edges of individual flows are brighter than both the flow surface and the substrate plain. Width of these bright stripes is typically 2-4 pixels (150...300 m), about cross-track (East-West) resolution of the image. It means that the apparent width is larger than the width of surface features responsible for this brightening. Full resolution images from all 3 cycles of Magellan survey are available for this site. We used them to measure average and standard deviation of normalized radar backscatter for 3-pixels-wide area along the edge marked by arrows in Fig. 1. For comparison the same was dome for typical smoothest areas on the flow and on the adjacent plain. The results are shown in **Fig. 2**. We used these measurements to constrain height of topographical step associated with the flow boundaries.

Tab. 1

Cycle	Incidence angle	Look direction	Cross-track resolution
1	$\theta_1 = 45^0$	left	w_1 = 125 m (w_1 = 225 m)
2	$\theta_2 = 25^0$	right	w_2 = 225 m
3	$\theta_3 = 24^0$	left	w_3 = 230 m

Radar incidence angle (θ) and cross-track resolution (w) are listed in **Tab. 1**. For Cycle 1, the measured stripe along the edge is wider than the image resolution, so its width (3 pixels = 225 m) should be used instead of resolution in the following considerations.

Model. Radar backscatter from the edge of the flow is enhanced because of (A) increased small-scale roughness or inhomogeneity of the surface, and (B) step-like topography associated with the edge. The latter is illustrated by **Fig. 3**. The step enhances reflected radar signal in a single radar delay span (cross-track resolution element) by the following two reasons: (B1) geometrical widening of surface area within the delay span (cross-track resolution element), and (B2) enhancing of reflection at the portion of the surface faced toward the radar. Total relative increase in the radar cross-section at the edge ($\Delta\sigma/\sigma$) can be expressed as it is shown in **Tab. 2**. The geometrical term (B1) is easy to express through the step height h. For the right look (cycle 2), geometrical effect (B1) leads to darkening, and reflectance term (B2) is negligibly small (Tab. 2). For the left look (cycles 1 and 3) we expressed the reflectance term (B2) through h and dimensionless factor $E(\theta)$ that depends on exact shape of the step and on scattering properties of the surface. We supposed that relative enhancement of radar backscatter due to roughness (A) is the same for all cycles. Of course, this is a rough approach, however its accuracy is high enough in comparison to ambiguity due to unknown step profile.

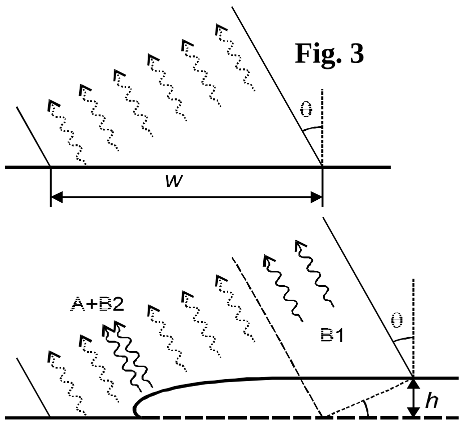

Fig. 3

To estimate a reasonable range for values of $E(\theta)$ we considered a family of step profiles described by power low functions with the exponent μ

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Tab. 2

Cycle	A + B1 + B2 ≈ Δσ / σ
1	$\frac{A}{w_1}+\frac{h}{w_1}\frac{1}{\tan\theta_1}+\frac{h}{w_1}E(\theta_1)\approx 1.14$
2	$\frac{A}{w_2}-\frac{h}{w_2}\frac{1}{\tan\theta_2}\approx 0.26$
3	$\frac{A}{w_3}+\frac{h}{w_3}\frac{1}{\tan\theta_3}+\frac{h}{w_3}E(\theta_3)\approx 1.40$

ranged in the interval $0 < \mu < 1$. **Fig. 4** shows selected profiles from this family (vertical scale is exaggerated, corresponding values of μ are shown in the Figure). We believe that this family covers all reasonable simple kinds of step shapes. We supposed that the scattering properties of the surface in the small scale are uniform and described by properly normalized global average backscattering function of Venus [4]. We estimated *E* as an integral of backscatter along the profile. Results at two incidence angles $\theta = 24^0$ and $\theta = 45^0$ are plotted against parameter μ in **Fig. 5**. The results are not sensitive to the particular choice of reasonable backscattering function.

Results. Approximate equations listed in Tab. 2 with parameters listed in Tab. 1 match when ***h*** **≈ 20 m** ... **40 m**.

Discussion. There are many sites on Magellan mosaics, where brightened edges of lava flows are seen, but for few of them data from all 3 cycles are available. The estimation of *h* made above can be done with data from Cycles 1 and 2 (or 3 and 2) only. The third set of measurements cannot improve the estimation, but it was useful to check consistency of the model.

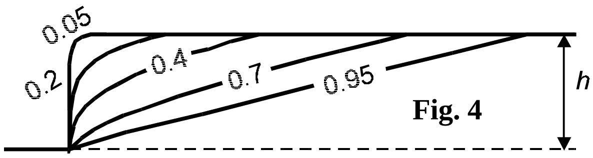

Fig. 4

If there are data from one cycle only, it is possible to estimate an upper limit for the height neglecting the radar backscatter enhancement due to roughness ($A = 0$).

Edges of majority of lava flows on Venus, including all sheet flow fields [5], are *not* brightened. The *absence of brightening* puts an *upper limit* for height of the step on their edges. For all Magellan high-quality images this limit only weakly depends on view geometry. However it strongly depends on radar backscatter difference on both sides of the edge, that is on relative contrast of the flow. For a typical case this dependence is plotted in **Fig. 6**.

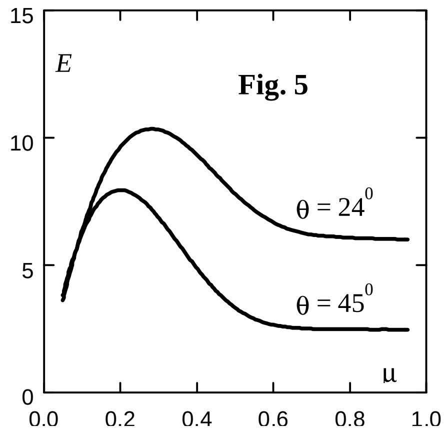

Fig. 5

Future work. Investigation of dependence of edge brightening on edge azimuth might help to constrain step profiles, which would increase the accuracy of the step height measurements. Estimations of the step height at the flows edges could be used to constrain lava viscosity and eruption rate. It is interesting to compare the step height estimations for lava flows of different radar signature and different edge sinuosity.

The method of subresolution clinometry, illustrated on flow edges, can be used for height estimation at other small steep slopes on Venus, if there is any a priori suggestion about slope profile.

References.

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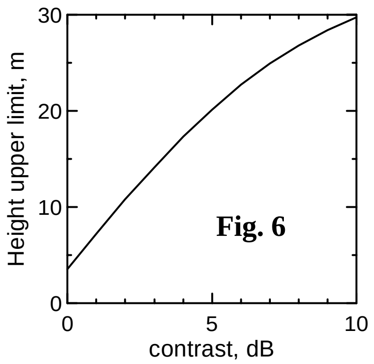

Fig. 6